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*W.R.D.*

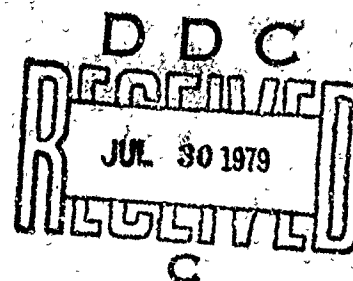
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# Project Report

NLP-13

## Vibration Survey on the NASA White Sands Steam Ejector

W. R. Davis



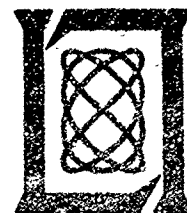
5 March 1979

Prepared for the Department of the Navy  
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### Lincoln Laboratory

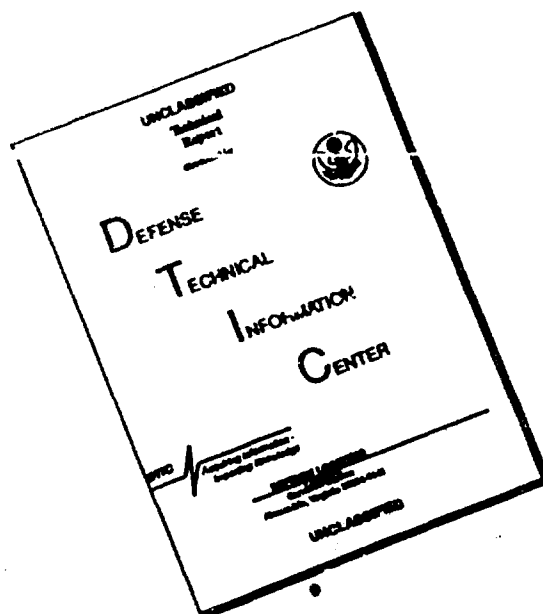
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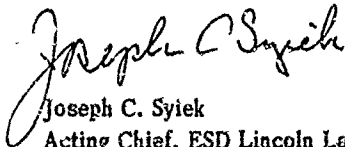
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This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER



Joseph C. Syiek  
Acting Chief, ESD Lincoln Laboratory Project Office

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
LINCOLN LABORATORY

VIBRATION SURVEY ON THE NASA  
WHITE SANDS STEAM EJECTOR

W. R. DAVIS  
Group 73

PROJECT REPORT NLP-13

5 MARCH 1979

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### Abstract

Vibration and dynamic pressure measurements were made on a large steam ejector at the NASA White Sands Test Facility. Acceleration measurements were made on the ejector foundation to determine how much vibration was transmitted to the ground, and dynamic pressure measurements were made in the ejector tube to provide a basis for future scaling of the vibration data to a larger size ejector. Spectral analyses are presented for both the accelerations and pressures.

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## INTRODUCTION

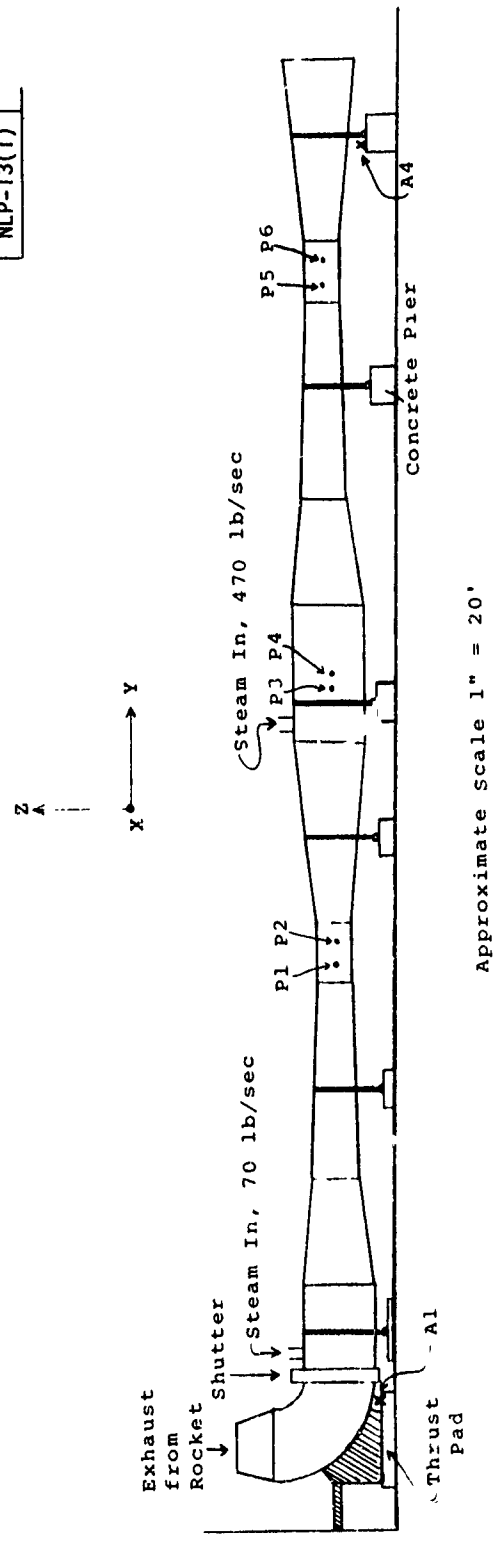
Lincoln Laboratory has made environmental measurements on a steam ejector at a rocket test stand at the NASA Lyndon B. Johnson Space Center White Sands Test Facility in November 1977. Acceleration measurements were made on the foundation piers for the ejector to determine how much vibration was induced into the ground, and internal pressure measurements were made to provide a basis for future scaling of the vibration levels to larger size ejectors. This report describes the NASA steam ejector, the test instrumentation, and the spectral analyses of the measurements.

## STEAM EJECTOR DESCRIPTION

The ejector, which is part of NASA test stand No. 401, is shown in Figures 1-4. It consists of two converging-diverging nozzle stages in series with a total length of about 180 ft. To allow for thermal expansion, the ejector supports are not constrained in the flow direction except at one thrust pad at the inlet end of the ejector (see Figure 1). On five of the concrete support piers, the ejector rests on tracked wheels. On the last pier at the exit end, the wheels have been replaced with teflon slides to alleviate a fatigue problem in the support ring at that point.

The thrust pad sits on a 3 ft thick concrete floor with vertical walls on three sides. The remaining piers are sunk about 1 ft in the soil. Soil samples taken during construction of the site were a mixture of sandy silt, gravel, and cobbles. No bedrock was found.

Steam is supplied by three rocket steam generators which evaporate water injected downstream of alcohol-liquid oxygen burners. The generators are located in a corrugated steel shed about 170 ft from the ejector, as shown in Figures 2 and 3. Steam is fed to both stages of the ejector - at 70 lb/sec to the first stage, and at 470 lb/sec to the second stage. Inlet steam conditions are approximately 285 psig static pressure and 500°F. Figures 2 and 3



- Pressure Gauge Locations
- x Accelerometer Locations

Fig.1. Steam ejector transducer locations.

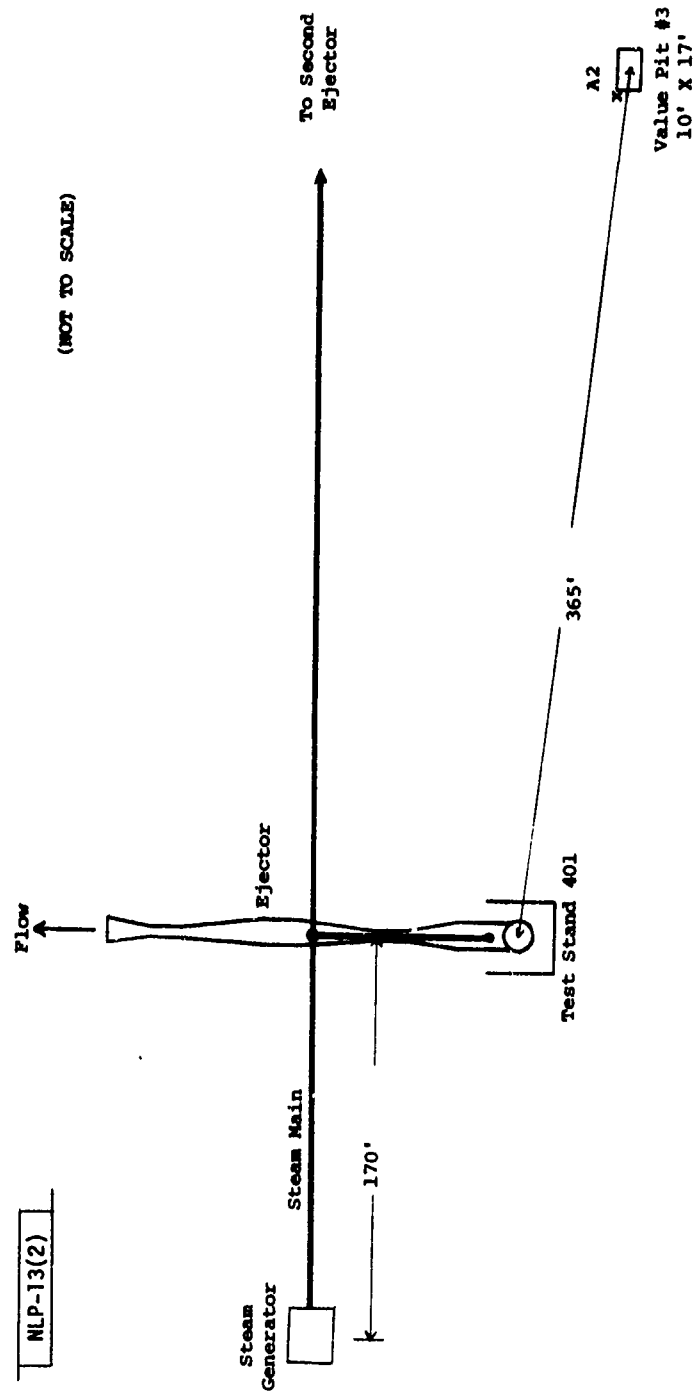


Fig. 2. Steam ejector site — plan view.





Fig. 3. Ejector and steam generator.

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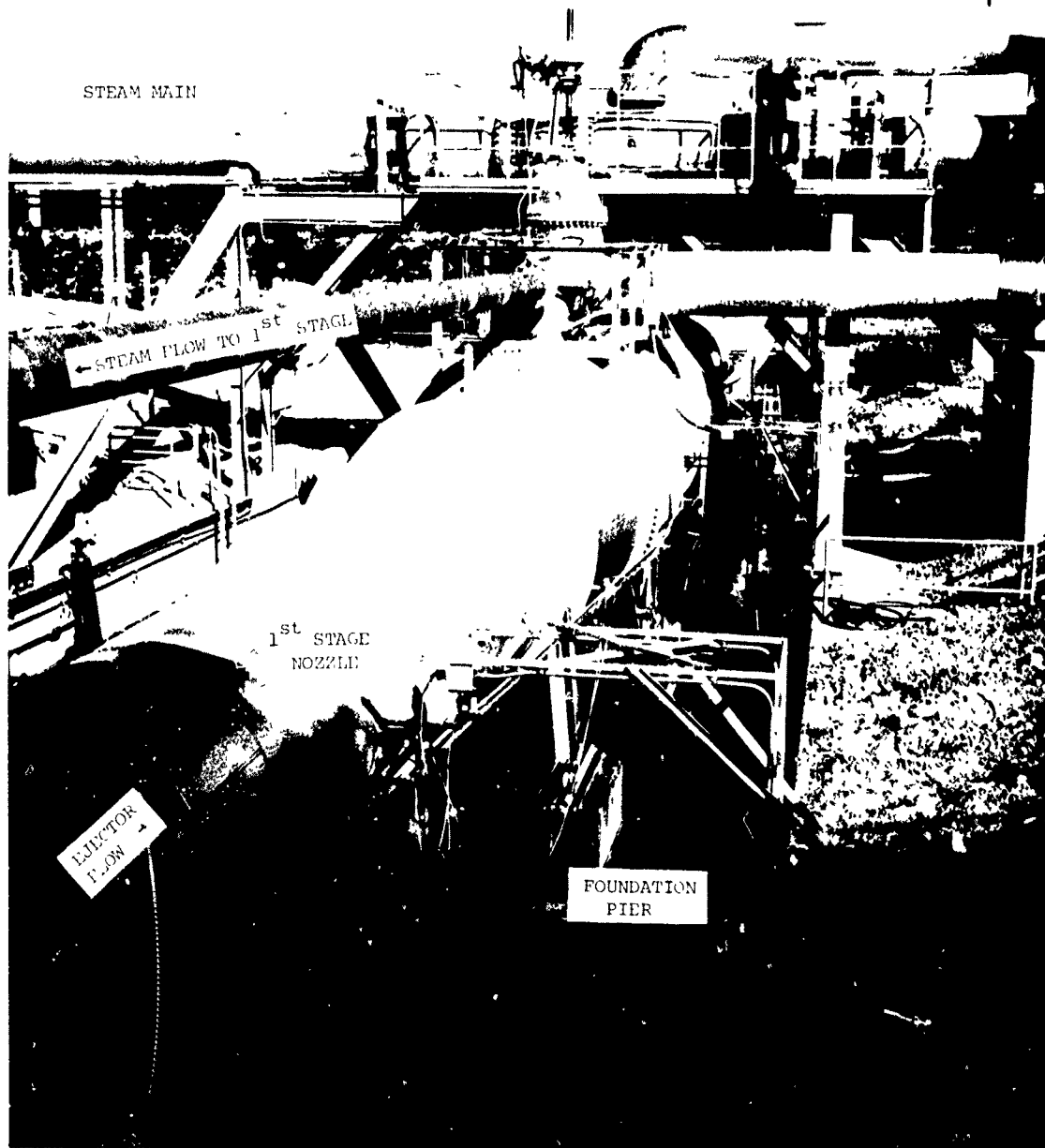


Fig. 4. Ejector steam supply and support details.

show the steam main continuing on past the ejector. It connects to another ejector which is not shown in the figures and was not in use during the tests. In Figure 3 all but the exhaust end of the ejector is hidden by the surrounding embankment.

#### TEST INSTRUMENTATION AND PROCEDURE

Two triaxial blocks of BBN model 501 accelerometers were placed on the ejector foundation. Accelerometer triad A1 was mounted on the thrust pad as shown in Figures 1 and 5, and accelerometer triad A4 was mounted on the last pier at the exit end of the ejector as shown in Figure 1. Accelerometer triad A2 was three BBN model 510 seismic accelerometers mounted in a triaxial configuration on the walls of a 6.5 ft deep concrete pit known as valve pit No. 3. See Figures 2 and 6. The pit was about 360 ft from the ejector thrust pad, and this location was chosen to permit measurement of the attenuation of the vibration transmitted through the soil.

Dynamic pressure gauges were placed at six locations on the ejector as shown in Figure 1. They were Celesco model PLC strain gauge types with maximum pressure ratings between 20 and 30 psi. Since the pressure gauges were only rated at 250°F, and the steam had a maximum temperature of 500°F, the gauges were isolated from the ejector wall by 24 in lengths of 1/2 in steel pipe as shown in Figure 7. Accelerometer A3, a BBN model 501, was mounted to pressure gauge P5 to determine pressure errors caused by vibration of the pressure gauges. In the figure, the accelerometer is hidden beneath the tape around the pressure gauge.

Both the accelerometer and pressure gauge signals were amplified with variable gain voltage amplifiers and recorded on a 14-track FM tape recorder.

Data was recorded during two ejector firings. All transducers except A4 were recorded during a 10 min firing on 9 November 1977, and A4 only was recorded during a 3 min firing on 10 November 1977. Recordings were also made with the ejector not operating to determine the background noise produced by the transducer-amplifier-tape recorder combination.

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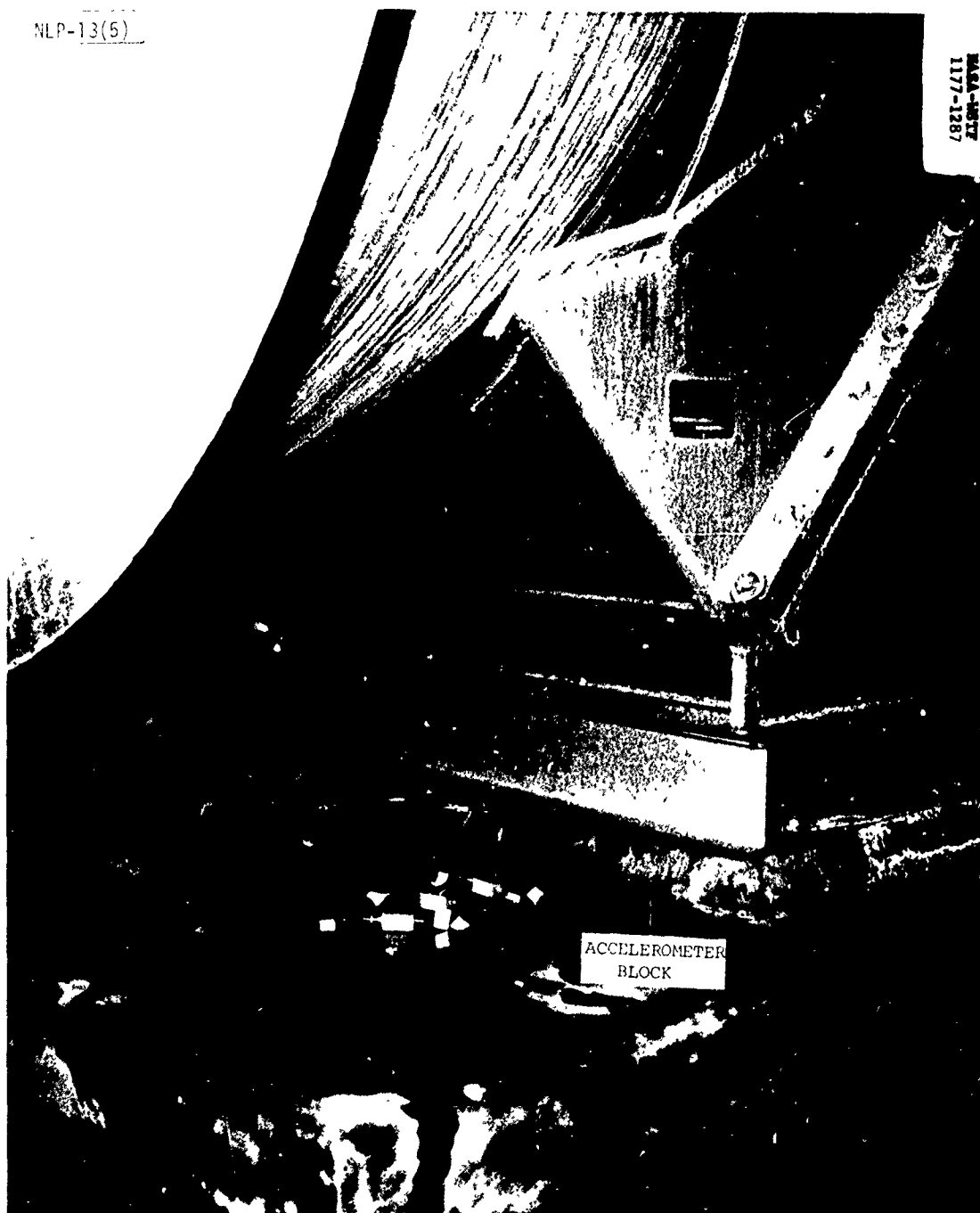


Fig. 5. Ejector thrust pad.

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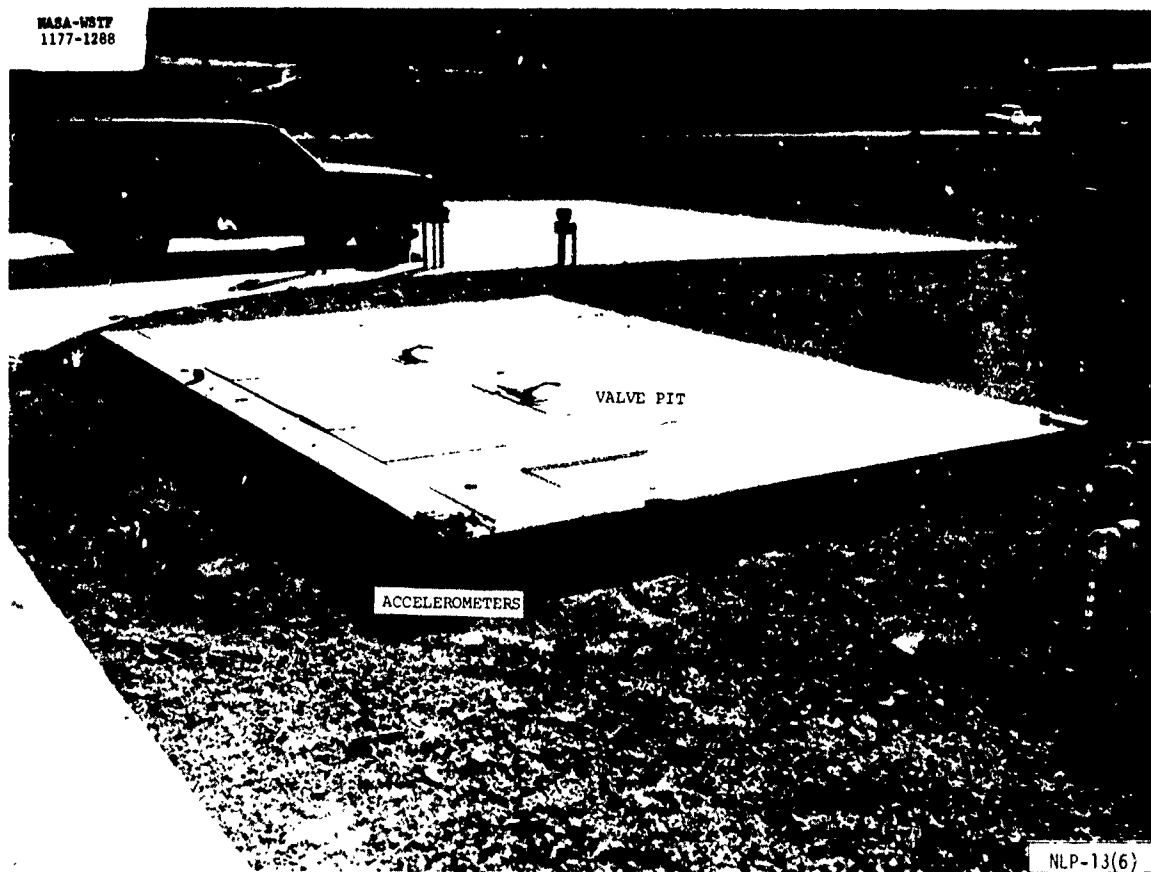


Fig. 6. Valve pit #3.

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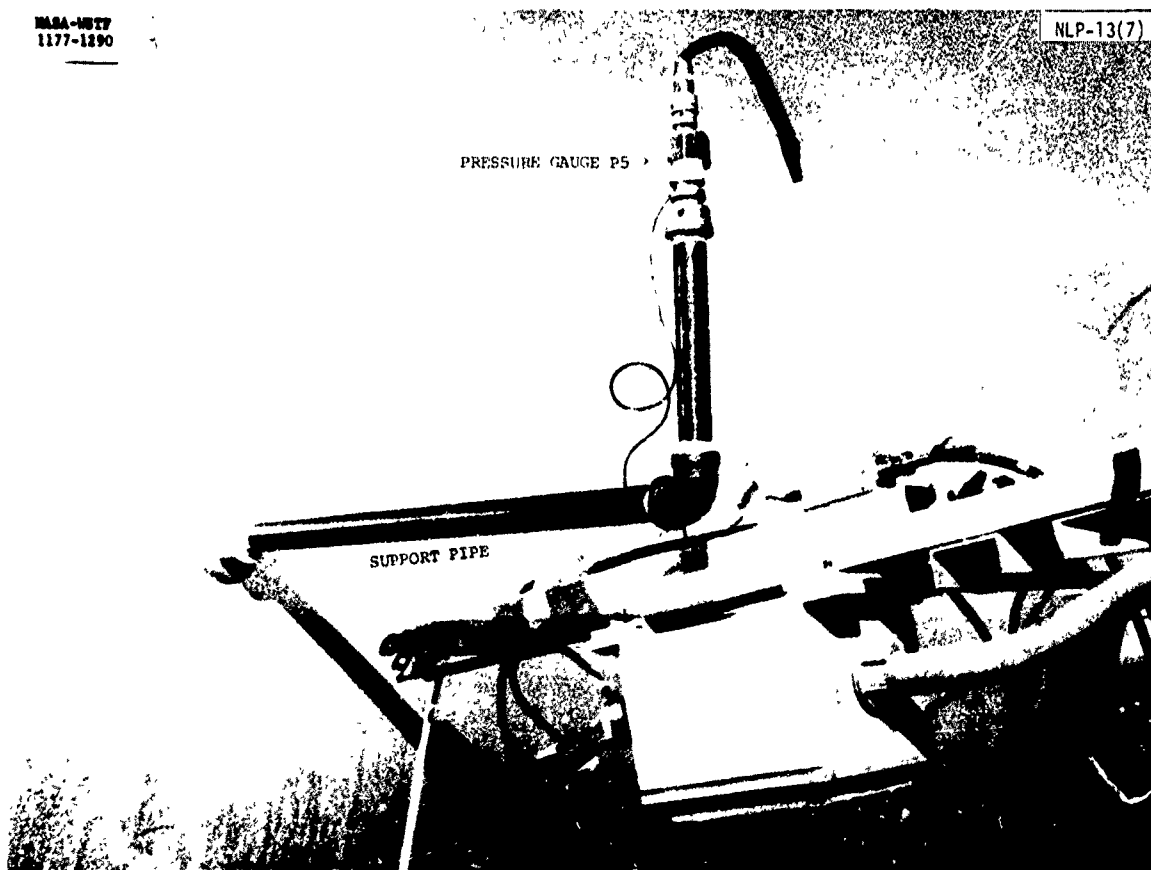


Fig. 7. Typical pressure gauge installation.

## DATA ANALYSIS

All data were analyzed on a constant bandwidth, real-time spectral analyzer in either of two analysis ranges: 0.25-100 Hz, or 2.5-1000 Hz. The analysis bandwidths were 0.25 and 2.5 Hz, respectively. Spectra from four 4 sec time segments were averaged for each low frequency plot, and thirty-two 0.4 sec time segments were averaged for each high frequency plot. The plots were calibrated in power spectral density (PSD) units.

## RESULTS

PSD results for accelerometers A1X, Y, and Z on the thrust pad are shown in Figures 8-10. The vibration levels were near the lower limit of resolution of the accelerometers, and the PSD curves were barely above the noise floor. Peaks in the spectra at 60 Hz and its harmonics appeared in both the vibration and background spectra, and they should be ignored. Aside from these peaks, levels were  $10^{-6} \text{ g}^2/\text{Hz}$  or lower.

PSD's for accelerometers A4X and A4Y on the last support pier are shown in Figures 11 and 12, and the levels are considerably higher. The PSD's were well above the noise floor at most frequencies and the highest response levels were about  $10^{-3} \text{ g}^2/\text{Hz}$ . Because the data from accelerometer A4Z was intermittent, no accurate spectra could be generated. Apparently, the vibration level was high enough to cause a malfunction in the accelerometer power supply. Examination of the acceleration time histories showed that the overall response of A4Z was higher than that of A4X or A4Y.

Accelerometers A2X, Y, and Z on the valve pit wall had much lower responses than the other accelerometers. PSD's are shown in Figures 13-15. The response levels were above the noise floor only at frequencies greater than 10 Hz. Spikes at 5 and 10 Hz were caused by instrument noise. During the ejector firings the valve pit was not in use, and there was no water flowing through it. Therefore, the vibration of the pit should have been due solely to steam ejector noise transmitted through the soil.

Soil vibration induced by the steam generators was not detectable on any of the accelerometers. This determination was possible since there was a delay between the time water flow started in the steam generators and the time

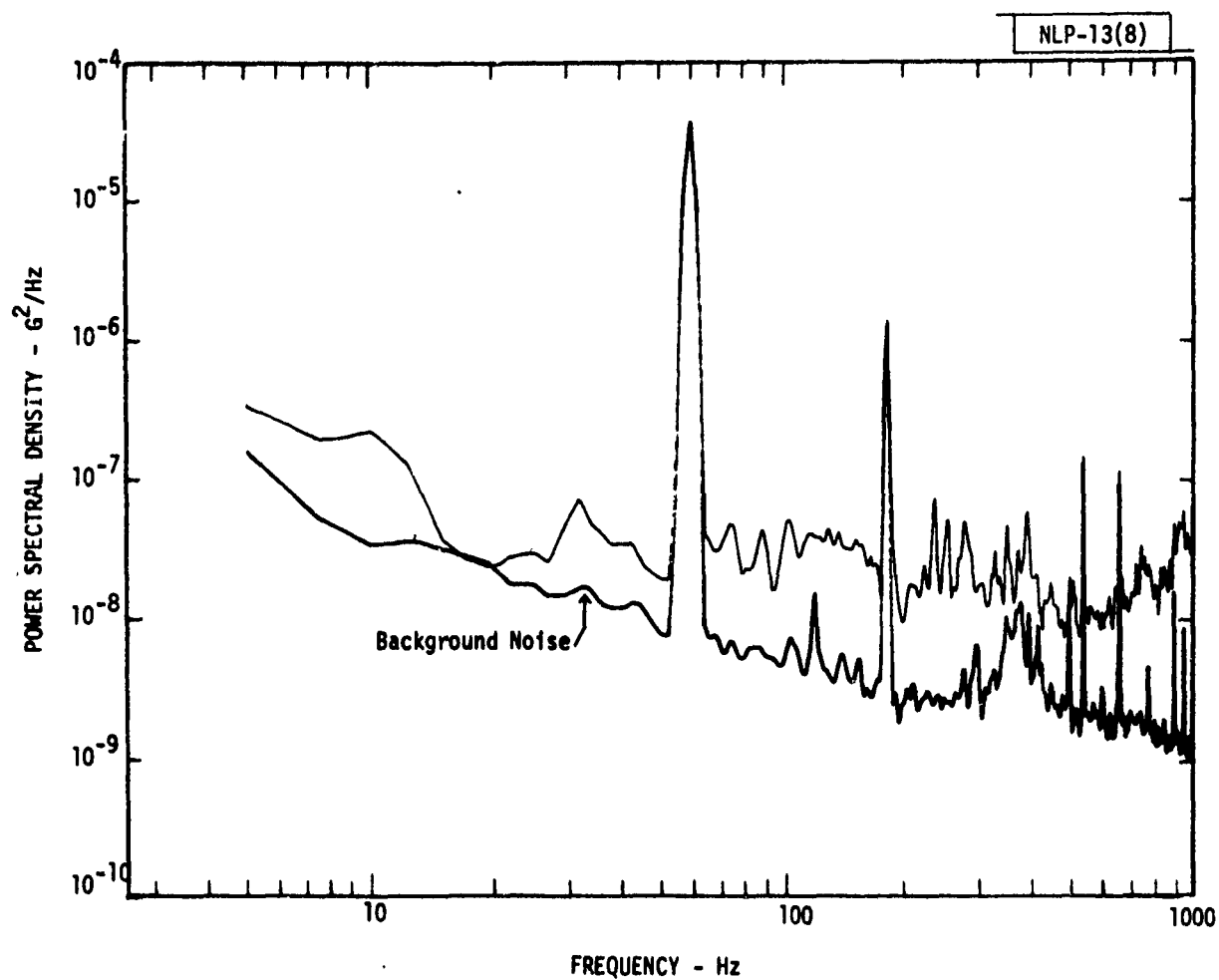


Fig. 8. Acceleration PSD - A1X.



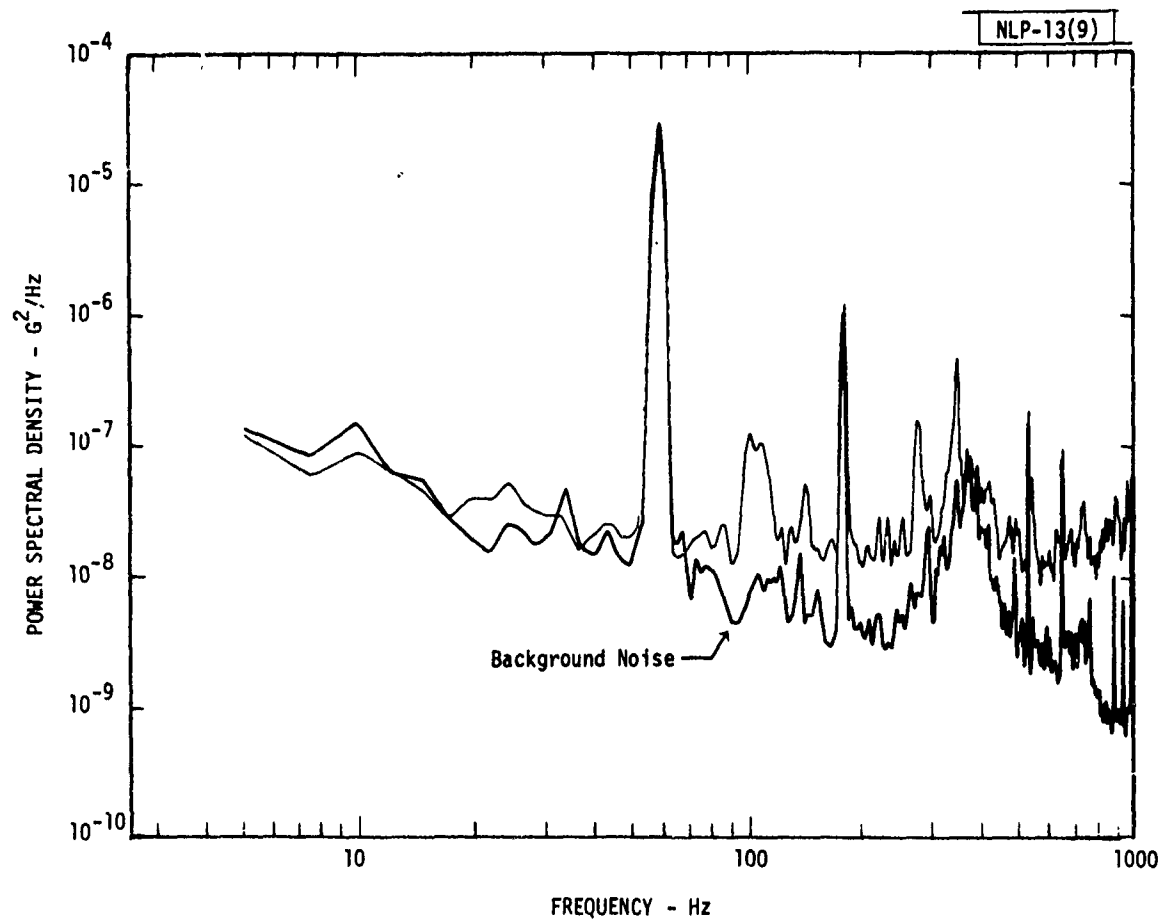


Fig. 9. Acceleration PSD - A1Y.

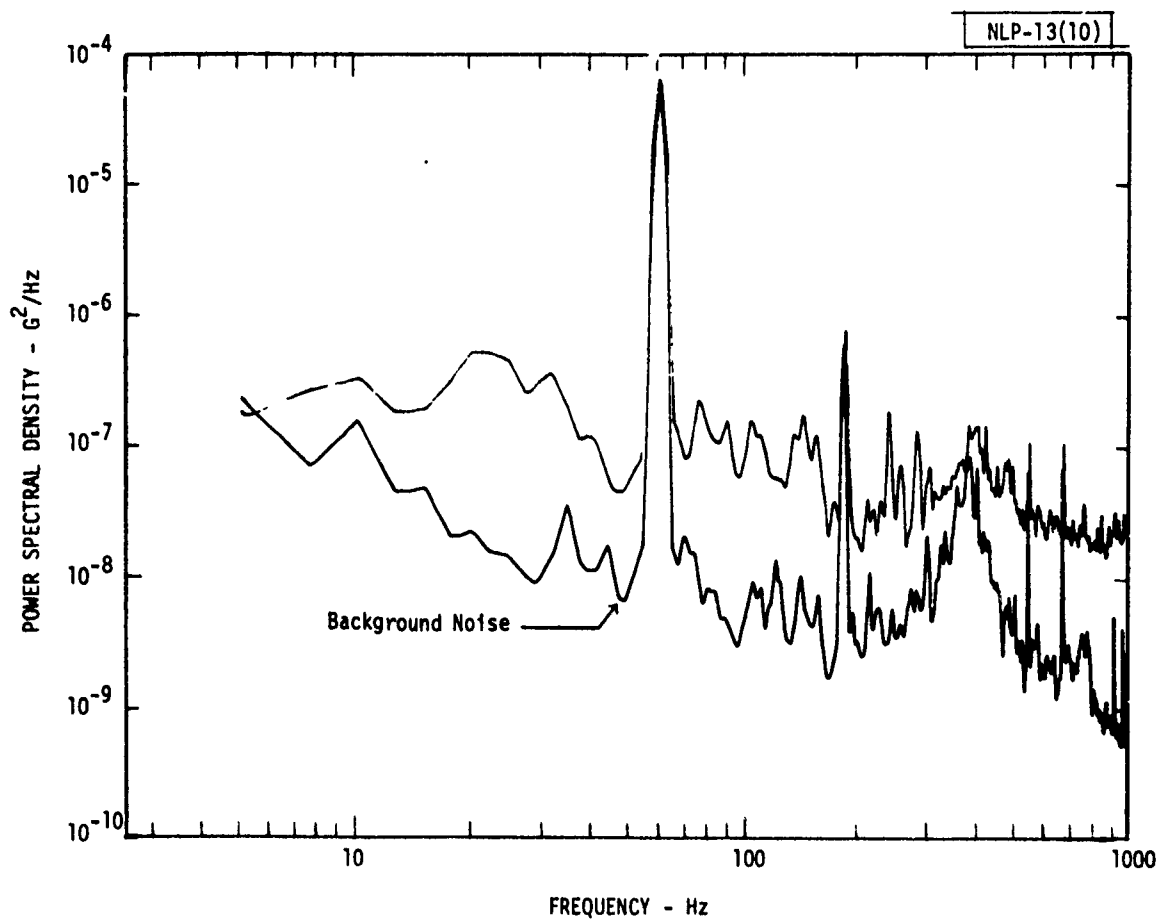


Fig. 1C. Acceleration PSD - A1Z.

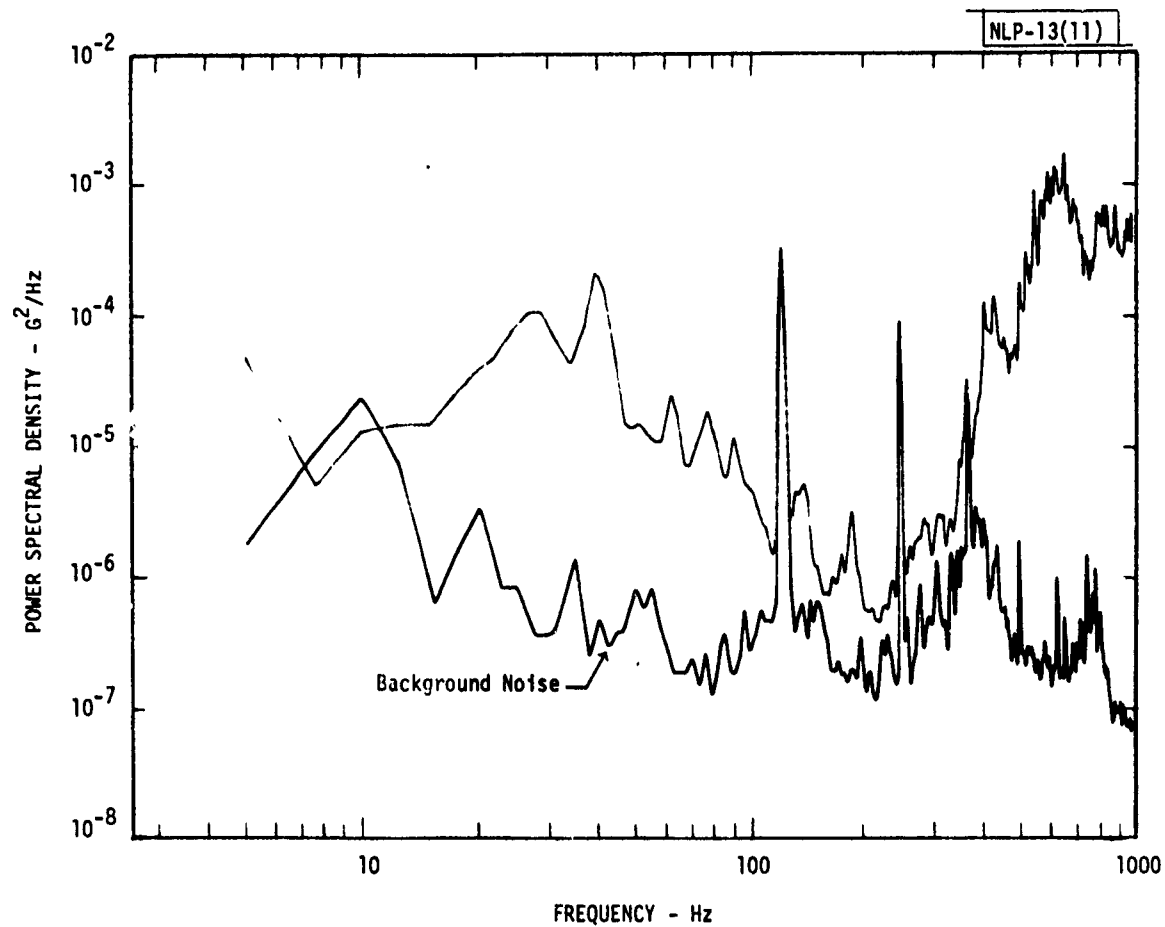


Fig. 11. Acceleration PSD - A4X.

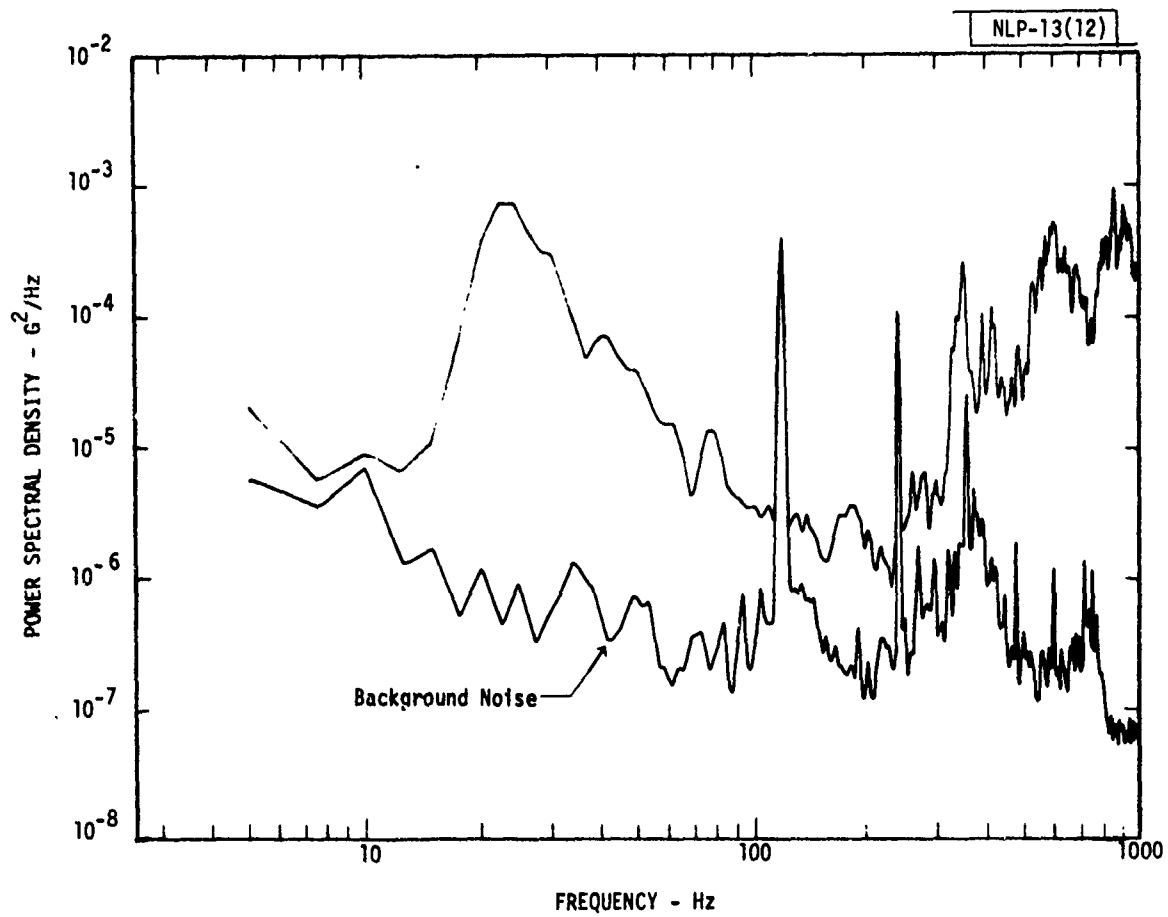


Fig. 12. Acceleration PSD - A4Y.

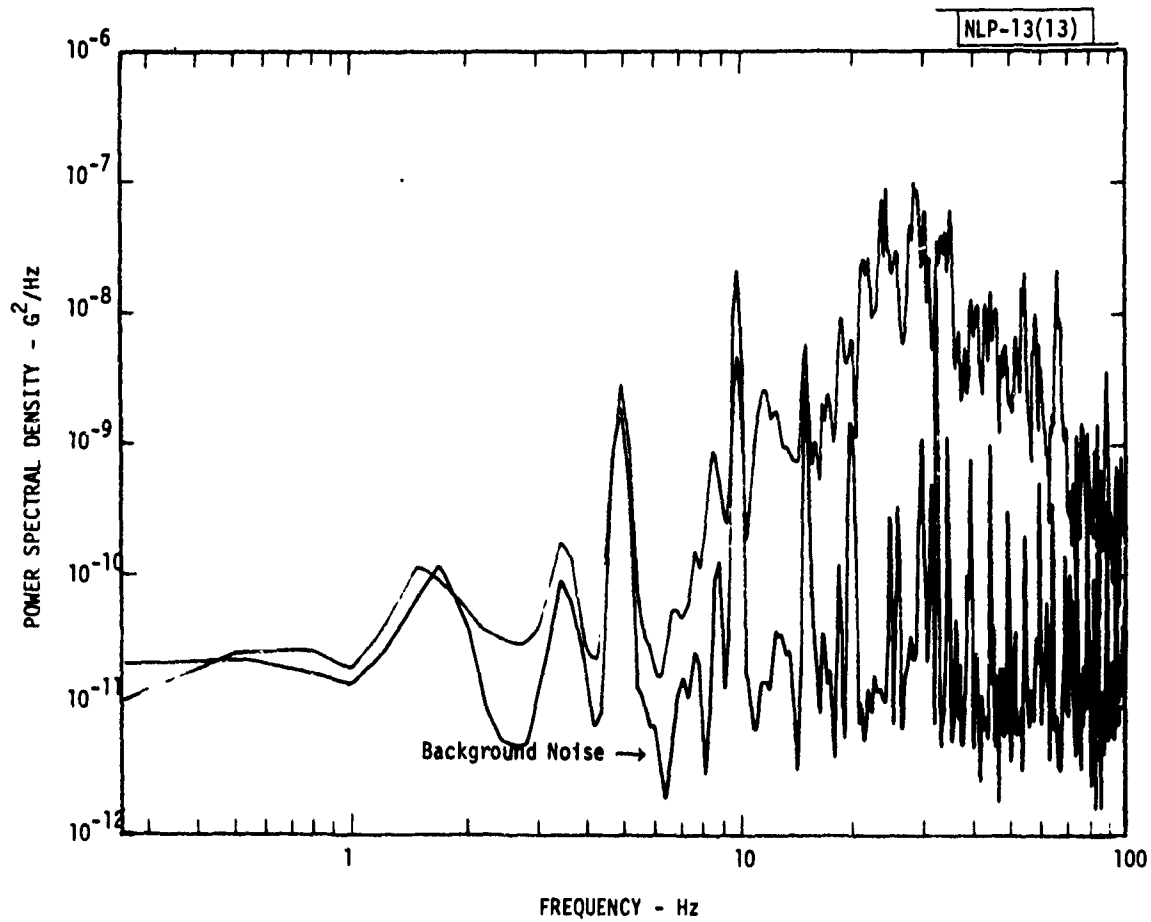


Fig. 13. Acceleration PSD - A2X.

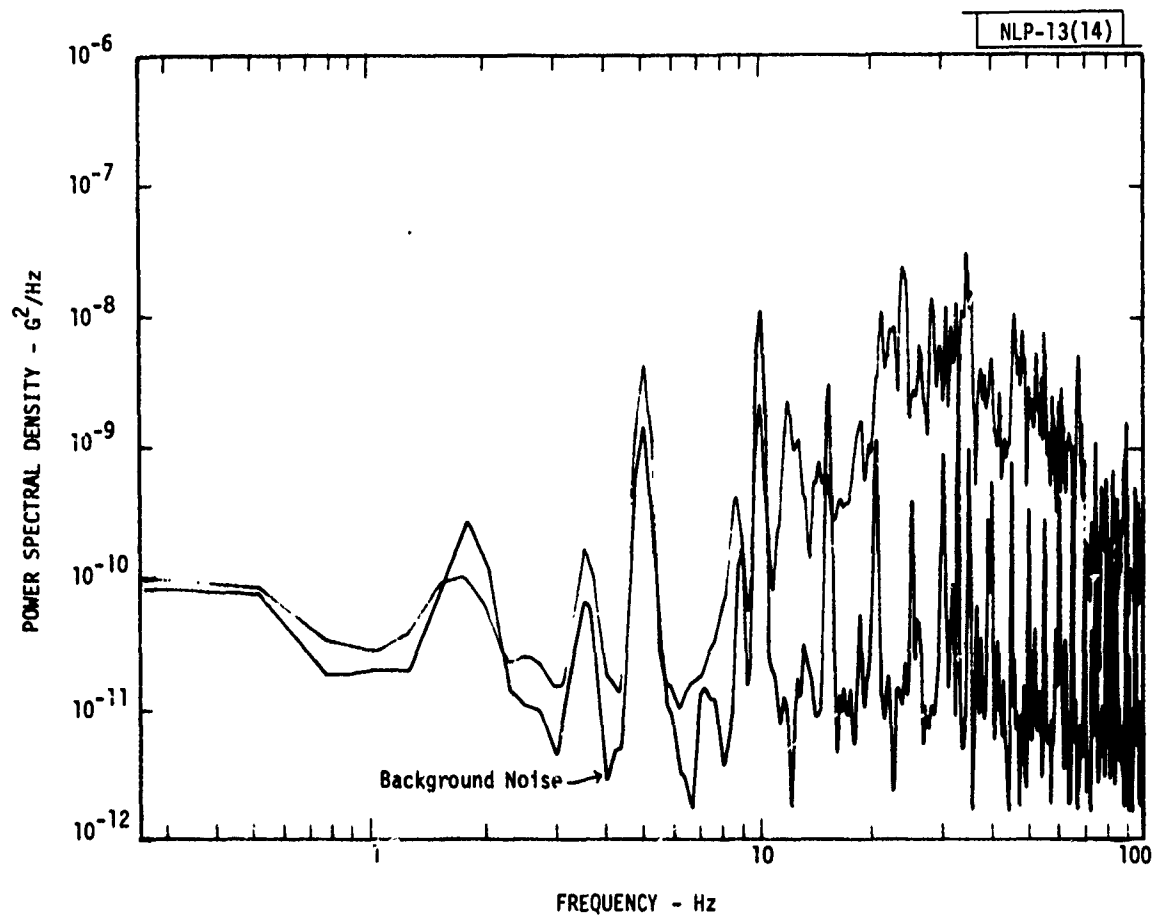


Fig. 14. Acceleration PSD - A2Y.

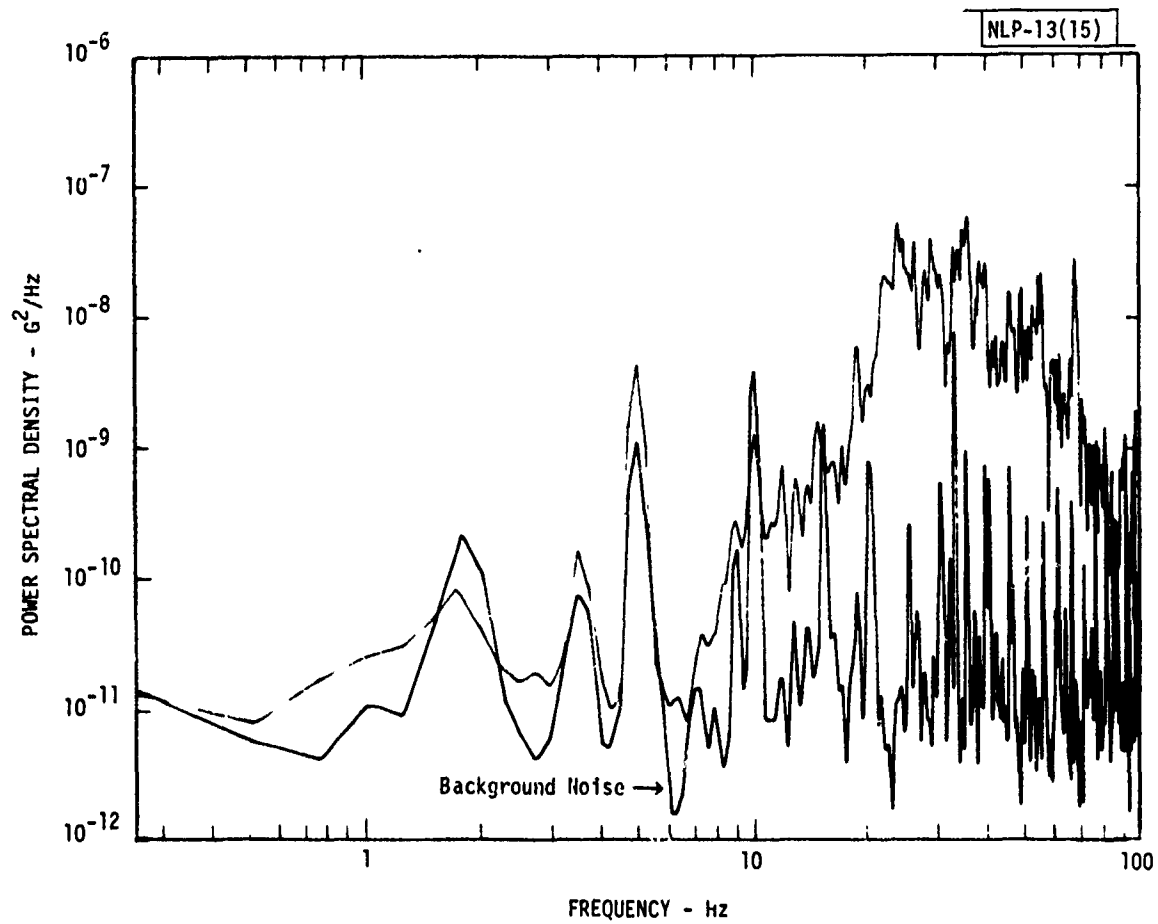


Fig. 15. Acceleration PSD - A2Z.

the steam flow started in the ejector. According to the NASA personnel, the major source of steam generator vibration was cavitating water flow through the venturis in the water supply lines. From personal observation, the acoustic output of the steam generators was much lower than that of the ejector.

Only two of the pressure gauges, P3 and P4, produced usable data. Gauges P5 and P6 did not survive the test, probably because of the high vibration levels. P1 and P2 had contaminated signals, probably because of faulty cables in the signal conditioning electronics. The vibration at the exit end of the diffuser was severe enough to break off the support pipe for P6 at its threaded attachment to the ejector, and to loosen the pipe for P5 at the same point. The P5 attachment pipe remained tight long enough to get usable data from accelerometer A3 mounted on P5. The peak acceleration level was about 170 g's, which according to the pressure gauge vibration sensitivity specification, would result in a maximum pressure error of 5%.

PSD's for pressure transducers P3 and P4 are shown in Figures 16 and 17. The pressure spectra were well above the noise floor for all frequencies except 60 Hz and its harmonics. Peaks at 180 and 500 Hz in both plots correspond to calculated organ pipe resonant frequencies for the pressure gauge support pipes. The peaks at 100 Hz may have been caused by acoustic resonances inside the ejector. The separation distance between P3 and P4 was 2 ft.

### CONCLUSIONS

Acceleration PSD levels for the ejector thrust pad (accelerometer A1) were several orders of magnitude lower than those for the exit-end support pier (accelerometer A4). This was probably due to the much greater mass of the thrust pad and the higher excitation forces existing at the exhaust end of the ejector due to the high speed turbulent flow exiting the ejector pipe. At 365 ft from the thrust pad on the valve pit (accelerometer A2) spectra levels were greatly attenuated. The shape of the spectra were also different: PSD's for the thrust pad were fairly flat, while PSD's for the valve pit were flat below 10 Hz and had broad peaks centered at about 20 Hz. The spectra from A1 and A2 may be conservative because of poor signal-to-noise ratios. The pressure spectra were generally flat with levels below  $10^4 \text{ (n/m}^2\text{)}^2/\text{Hz}$ .



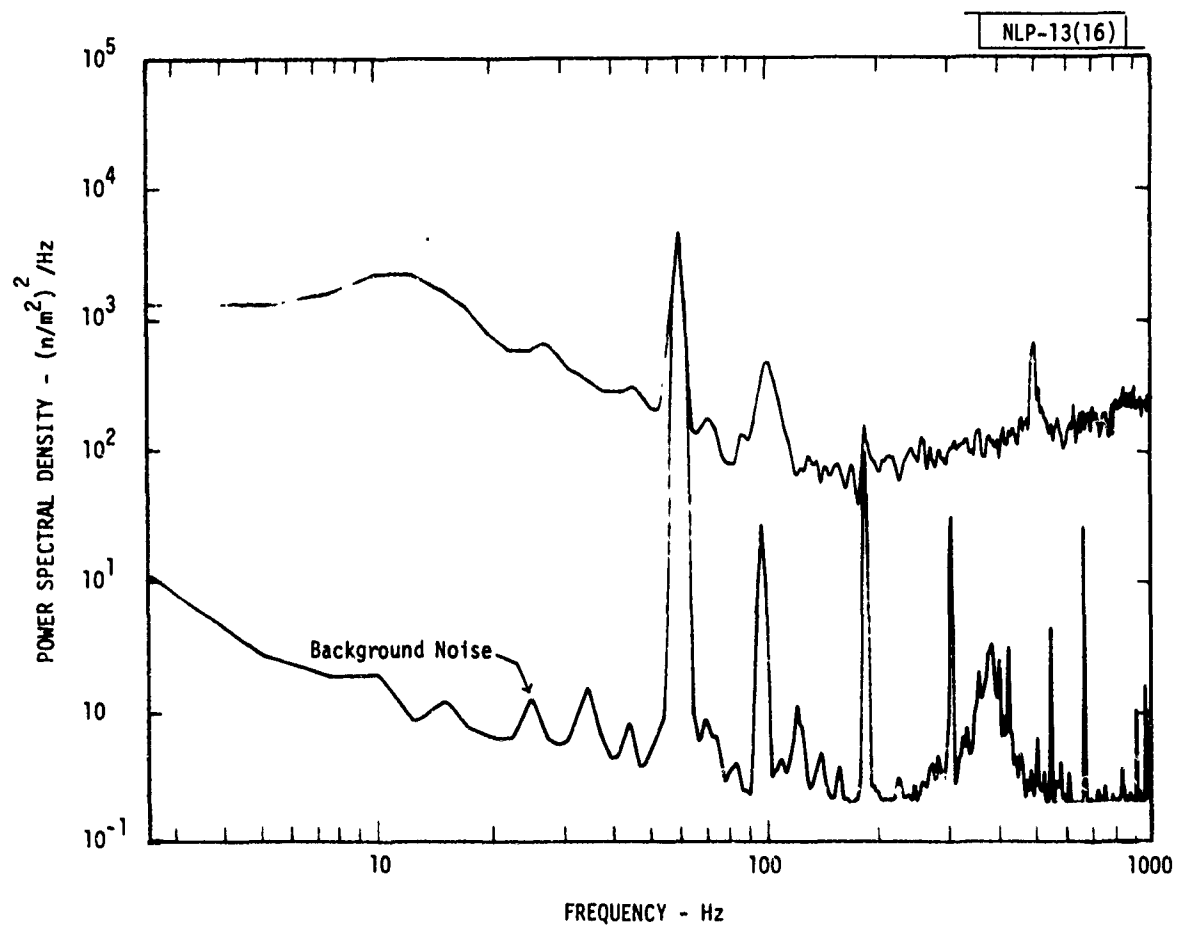


Fig. 16. Pressure PSD - P3.

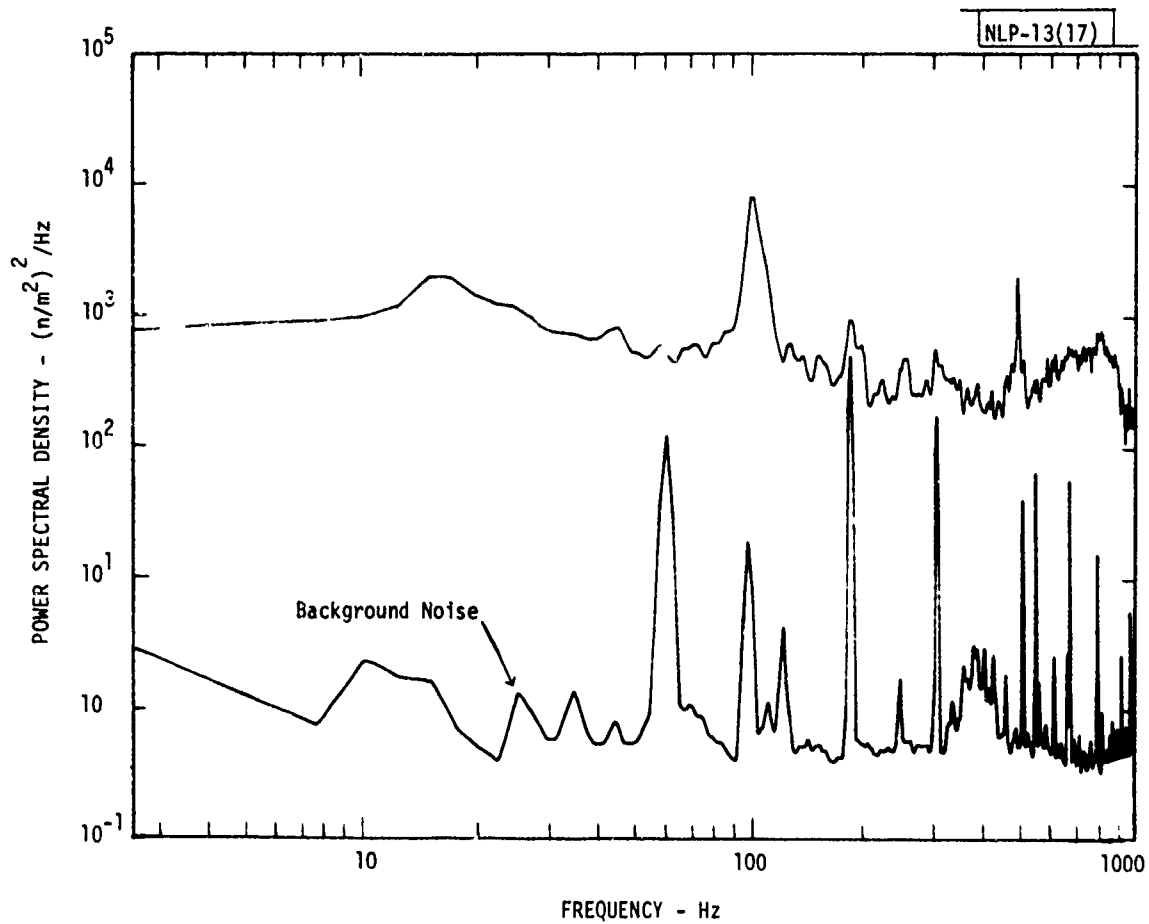


Fig. 17. Pressure PSD - P4.

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